Charm weak decays at BESIII and STCF

Xiao-Rui Lyu
(*xiaorui@ucas.ac.cn*)

University of Chinese Academy Sciences

(On behalf of the BESIII collaboration and the STCF working group)

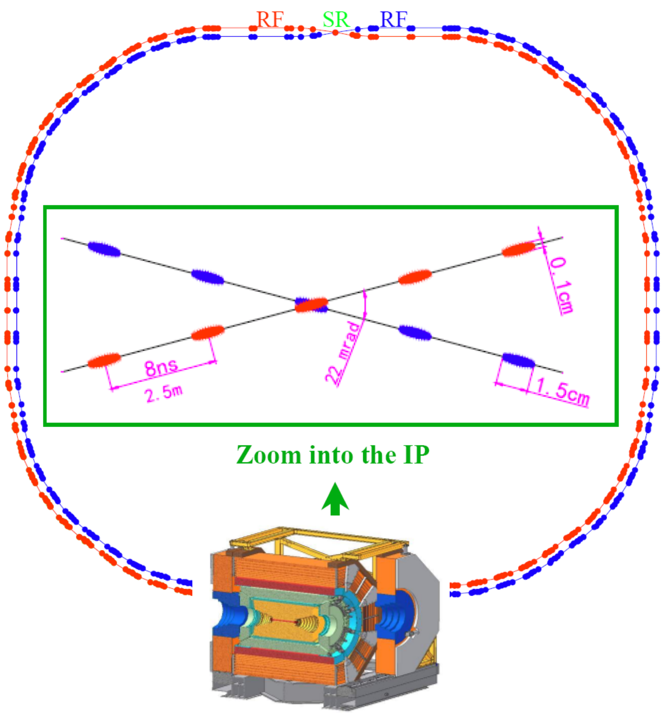
BEPCII and STCF in China

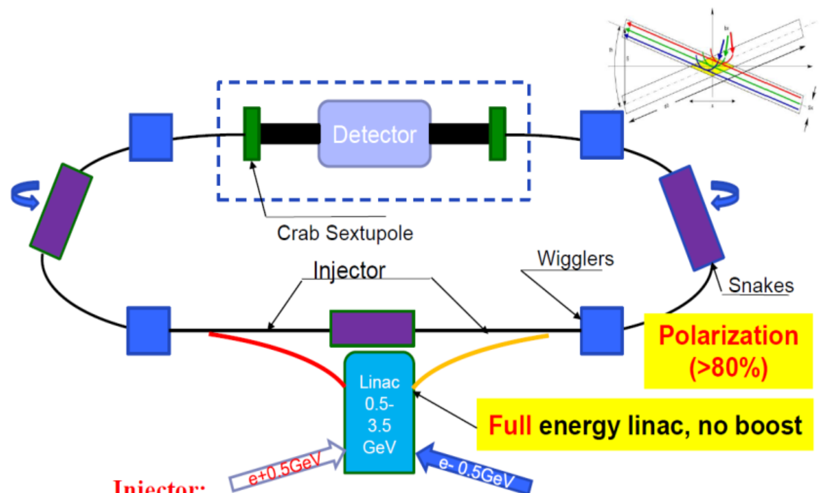
BEPCII

- **Peak luminosity 0.6-1×10^{33} cm^{-2}s^{-1} at 3.773 GeV**
- **Energy range E_{cm} = 2 – 4.6 GeV**
- No Polarization

Designed STCF

- **Peak luminosity 0.5-1×10^{35} cm^{-2}s^{-1} at 4 GeV**
- **Energy range E_{cm} = 2–7 GeV**
- **Potential to increase luminosity and realize beam polarization**



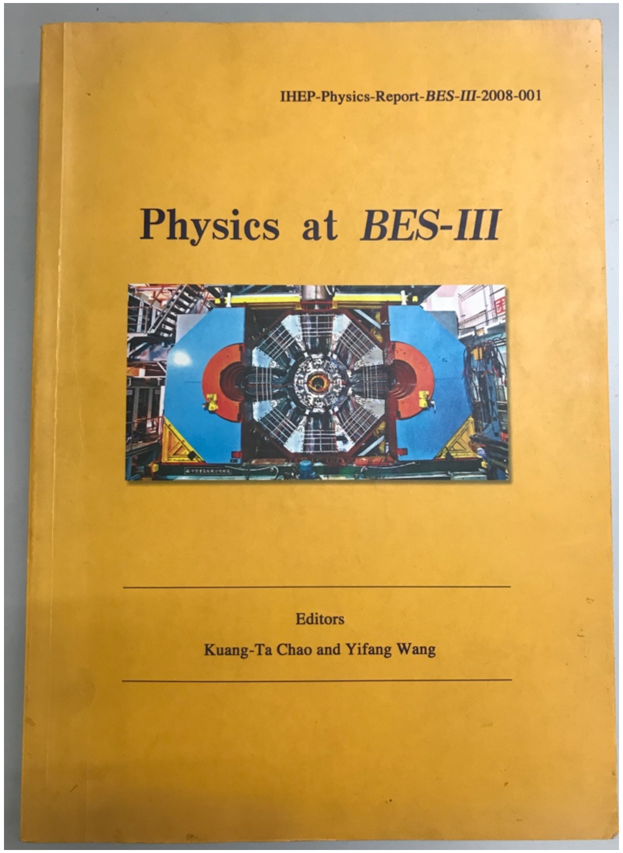


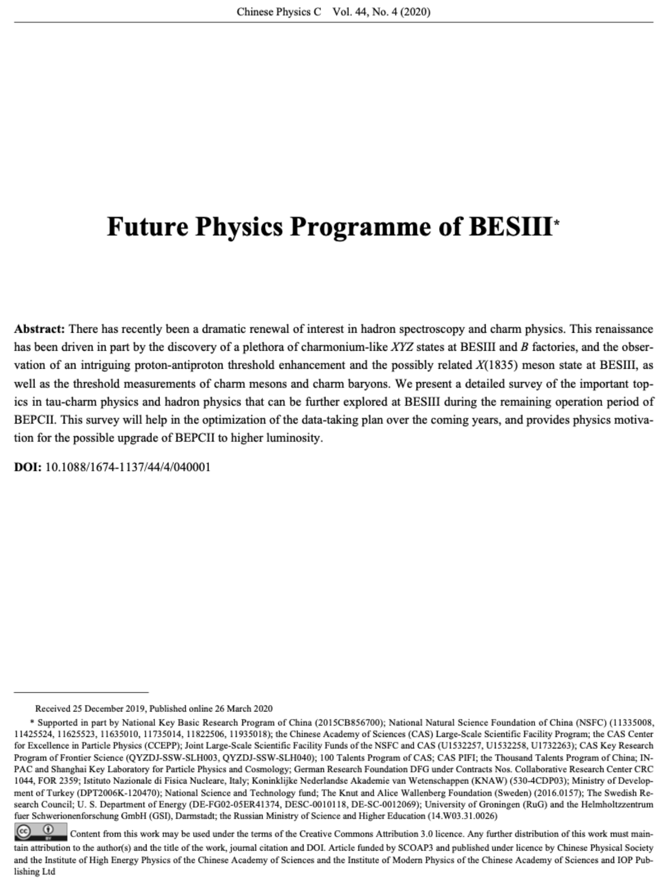
Injector:

- e+, a convertor, a linac and a damping ring, 0.5GeV
- e-, a polarized e- source, accelerated to 0.5GeV

1 ab^{-1} data expected per year

BESIII Physics





Chinese Physics C Vol. 44, No. 4 (2020)

Future Physics Programme of BESIII*

Abstract: There has recently been a dramatic renewal of interest in hadron spectroscopy and charm physics. This renaissance has been driven in part by the discovery of a plethora of charmonium-like *XYZ* states at BESIII and *B* factories, and the observation of an intriguing proton-antiproton threshold enhancement and the possibly related *X*(1835) meson state at BESIII, as well as the threshold measurements of charm mesons and charm baryons. We present a detailed survey of the important topics in tau-charm physics and hadron physics that can be further explored at BESIII during the remaining operation period of BEPCII. This survey will help in the optimization of the data-taking plan over the coming years, and provides physics motivation for the possible upgrade of BEPCII to higher luminosity.

DOI: 10.1088/1674-1137/44/4/040001

Received 25 December 2019, Published online 26 March 2020

* Supported in part by National Key Basic Research Program of China (2015CB856700); National Natural Science Foundation of China (NSFC) (11335008, 11425524, 11625523, 11635010, 11735014, 11822506, 11935018); the Chinese Academy of Sciences (CAS) Large-Scale Scientific Facility Program; the CAS Center for Excellence in Particle Physics (CCEPP); Joint Large-Scale Scientific Facility Funds of the NSFC and CAS (U1532257, U1532258, U1732263); CAS Key Research Program of Frontier Science (QYZDJ-SSW-SLH003, QYZDJ-SSW-SLH040); 100 Talents Program of CAS; CAS PIFI; the Thousand Talents Program of China; INPAC and Shanghai Key Laboratory for Particle Physics and Cosmology; German Research Foundation DFG under Contracts Nos. Collaborative Research Center CRC 1044, FOR 2359; Istituto Nazionale di Fisica Nucleare, Italy; Koninklijke Nederlandse Akademie van Wetenschappen (KNAW) (530-4CDP03); Ministry of Development of Turkey (DPT2006K-120470); National Science and Technology fund; The Knut and Alice Wallenberg Foundation (Sweden) (2016.0157); The Swedish Research Council; U. S. Department of Energy (DE-FG02-05ER41374, DESC-0010118, DE-SC-0012069); University of Groningen (RuG) and the Helmholtzzentrum fuer Schwerionenforschung GmbH (GSI), Darmstadt; the Russian Ministry of Science and Higher Education (14.W03.31.0026)

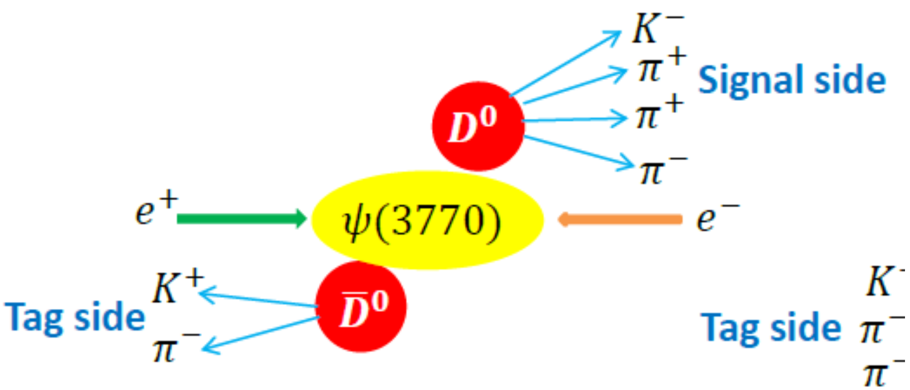
Int. J. Mod. Phys. A 24, S1-794 (2009) [arXiv:0809.1869 [hep-ex]].

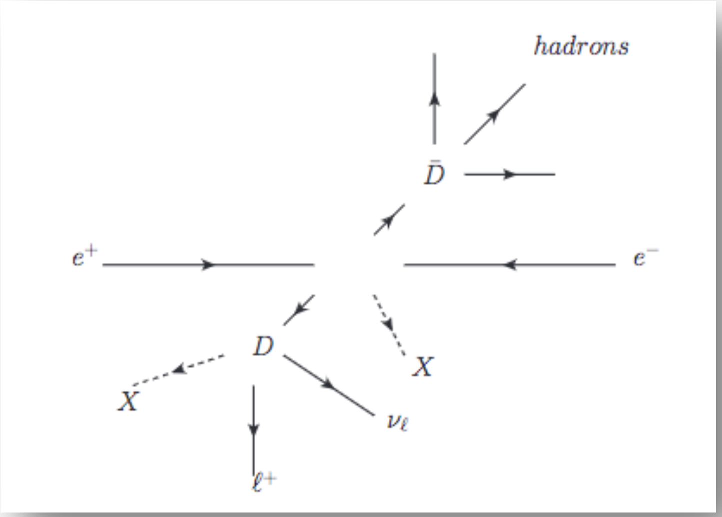
Chin. Phys. C 44, 040001 (2020) doi:10.1088/1674-1137/44/4/040001 [arXiv:1912.05983 [hep-ex]].

Facilities for Charm Study

- LHCb: huge x-sec, boost, 9 fb^{-1} now (x40 current B-factories)
- B-factories (Belle(-II), BaBar): more kinematic constrains, clean environment, ~100% trigger efficiency
- τ-charm factory : Low backgrounds and high efficiency; missing technique; Quantum correlations and CP-tagging are unique;
  - BESIII: 20 fb^{-1} at 3.77 GeV; 6 fb^{-1} at 4.18 GeV; 15 fb^{-1} @ 4.6-4.9 GeV
  - STCF : 4×10^9 pairs of $D^{\pm,0}$ and 10^8 Ds pairs per year
  - Highlighted Physics programs
    - Precise measurement of (semi-)leptonic decay (f_D, f_{Ds}, CKM matrix…)
    - $D^0 - \overline{D}^0$ mixing, CPV
    - Rear decay (FCNC, LFV, LNV….)
    - Excite charm meson states D_J, D_{sJ} (mass, width, J^{PC}, decay modes)
    - Charmed baryons (J^{PC}, Decay modes, absolute BF)
    - Light meson and hyperon spectroscopy studied in charmed hadron decays

Charmed meson decays





Precision measurement of CKM elements

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

- A precise test of EW theory
- New physics beyond SM?

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

BESIII + B factories + LQCD

Three generations of quark?

Unitary matrix?

BESIII + B factories + LHCb + LQCD

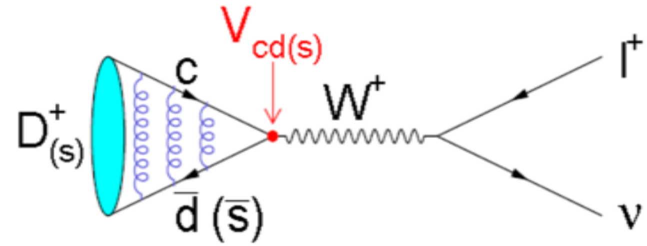
Expected precision < 2% at BESIII

A direct measurement of $V_{cd(s)}$ is one of the most important task in charm physics

$D_{(s)}$ (Semi-)Leptonic decay

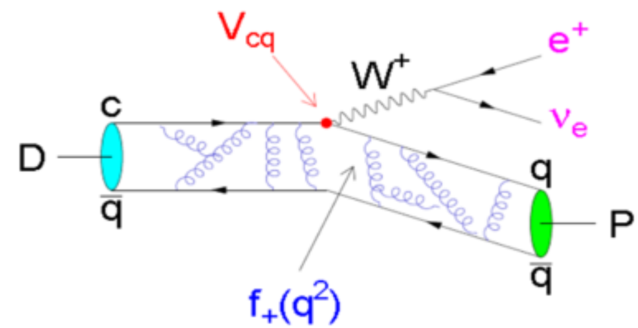
Purely Leptonic:

$$\Gamma(D^+_{(s)} \to \ell^+ \nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} \mid V_{cd(s)} \mid^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$



Semi-Leptonic:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs(d)}|^2 p^3_{K(\pi)} |f_+^{K(\pi)}(q^2)|^2$$



Directly measurement : $|V_{cd(s)}| \times f_{D(s)}$ or $|V_{cd(s)}| \times FF$

- Input $f_{D(s)}$ or $f^{k(\pi)}(0)$ from LQCD $\Rightarrow$ $|V_{cd(s)}|$
- Input $|V_{cd(s)}|$ from a global fit $\Rightarrow$ $f_{D(s)}$ or $f^{k(\pi)}(0)$
- Validate LQCD calculation of Input $f_{B(s)}$ and provide constrain of CKM-unitarity

$D_{(s)}$ Leptonic decay

	BESIII	BESIII	STCF	Belle II
Luminosity	2.9 fb^{-1} at 3.773 GeV	20 fb^{-1} at 3.773 GeV	1 ab^{-1} at 3.773 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$5.1\%_{\text{stat.}}$ $1.6\%_{\text{syst.}}$ [4]	$1.9\%_{\text{stat.}}$ $1.3\%_{\text{syst.}}$	$0.28\%_{\text{stat}}$	–
f_{D^+} (MeV)	$2.6\%_{\text{stat.}}$ $0.9\%_{\text{syst.}}$ [4]	$1.0\%_{\text{stat.}}$ $0.8\%_{\text{syst.}}$	$0.15\%_{\text{stat}}$	
$\lvert V_{cd}\rvert$	$2.6\%_{\text{stat.}}$ $1.0\%^{*}_{\text{syst.}}$ [4]	$1.0\%_{\text{stat.}}$ $0.8\%^{*}_{\text{syst.}}$	$0.15\%_{\text{stat}}$	
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	$20\%_{\text{stat.}}$ $10\%^{\dagger}_{\text{syst.}}$	$8\%_{\text{stat.}}$ $5\%_{\text{syst.}}$	$0.41\%_{\text{stat}}$	–
$\frac{\mathcal{B}(D^+\to\tau^+\nu_\tau)}{\mathcal{B}(D^+\to\mu^+\nu_\mu)}$	$21\%_{\text{stat.}}$ $10\%^{\dagger}_{\text{syst.}}$	$8\%_{\text{stat.}}$ $5\%_{\text{syst.}}$	$0.50\%_{\text{stat}}$	–
Luminosity	3.2 fb^{-1} at 4.178 GeV	6 fb^{-1} at 4.178 GeV	1 ab^{-1} at 4.009 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$2.8\%_{\text{stat.}}$ $2.7\%_{\text{syst.}}$ [5]	$2.1\%_{\text{stat.}}$ $2.2\%_{\text{syst.}}$	$0.30\%_{\text{stat}}$	$0.8\%_{\text{stat}}$ $1.8\%_{\text{syst}}$
$f_{D_s^+}$ (MeV)	$1.5\%_{\text{stat.}}$ $1.6\%_{\text{syst.}}$ [5]	$1.0\%_{\text{stat.}}$ $1.2\%_{\text{syst.}}$	$0.15\%_{\text{stat}}$	
$\lvert V_{cs}\rvert$	$1.5\%_{\text{stat.}}$ $1.6\%_{\text{syst.}}$ [5]	$1.0\%_{\text{stat.}}$ $1.2\%_{\text{syst.}}$	$0.15\%_{\text{stat}}$	
$f_{D_s^+}/f_{D^+}$	$3.0\%_{\text{stat.}}$ $1.5\%_{\text{syst.}}$ [5]	$1.4\%_{\text{stat.}}$ $1.4\%_{\text{syst.}}$	$0.21\%_{\text{stat}}$	–
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$2.2\%_{\text{stat.}}$ $2.6\%^{\dagger}_{\text{syst.}}$	$1.6\%_{\text{stat.}}$ $2.4\%_{\text{syst.}}$	$0.24\%_{\text{stat}}$	$0.6\%_{\text{stat}}$ $2.7\%_{\text{syst}}$
$f_{D_s^+}$ (MeV)	$1.1\%_{\text{stat.}}$ $1.5\%^{\dagger}_{\text{syst.}}$	$0.9\%_{\text{stat.}}$ $1.4\%_{\text{syst.}}$	$0.11\%_{\text{stat}}$	
$\lvert V_{cs}\rvert$	$1.1\%_{\text{stat.}}$ $1.5\%^{\dagger}_{\text{syst.}}$	$0.9\%_{\text{stat.}}$ $1.4\%_{\text{syst.}}$	$0.11\%_{\text{stat}}$	
$\overline{f}^{\mu\&\tau}_{D_s^+}$ (MeV)	$0.9\%_{\text{stat.}}$ $1.0\%^{\dagger}_{\text{syst.}}$	$0.6\%_{\text{stat.}}$ $0.9\%_{\text{syst.}}$	$0.09\%_{\text{stat}}$	$0.3\%_{\text{stat}}$ $1.0\%_{\text{syst}}$
$\lvert\overline{V}^{\mu\&\tau}_{cs}\rvert$	$0.9\%_{\text{stat.}}$ $1.0\%^{\dagger}_{\text{syst.}}$	$0.6\%_{\text{stat.}}$ $0.9\%_{\text{syst.}}$	$0.09\%_{\text{stat}}$	–
$\frac{\mathcal{B}(D_s^+\to\tau^+\nu_\tau)}{\mathcal{B}(D_s^+\to\mu^+\nu_\mu)}$	$3.6\%_{\text{stat.}}$ $3.0\%^{\dagger}_{\text{syst.}}$	$2.6\%_{\text{stat.}}$ $2.8\%_{\text{syst.}}$	$0.38\%_{\text{stat}}$	$0.9\%_{\text{stat}}$ $3.2\%_{\text{syst}}$

LQCD : 0.2%
(0.1% expected)

LQCD : 0.2%
(0.1% expected)

LQCD : 0.2%
(0.1% expected)

* assuming Belle II improved systematics by a factor 2

Stat. uncertainty is closed to theory precision
Sys. is challenging

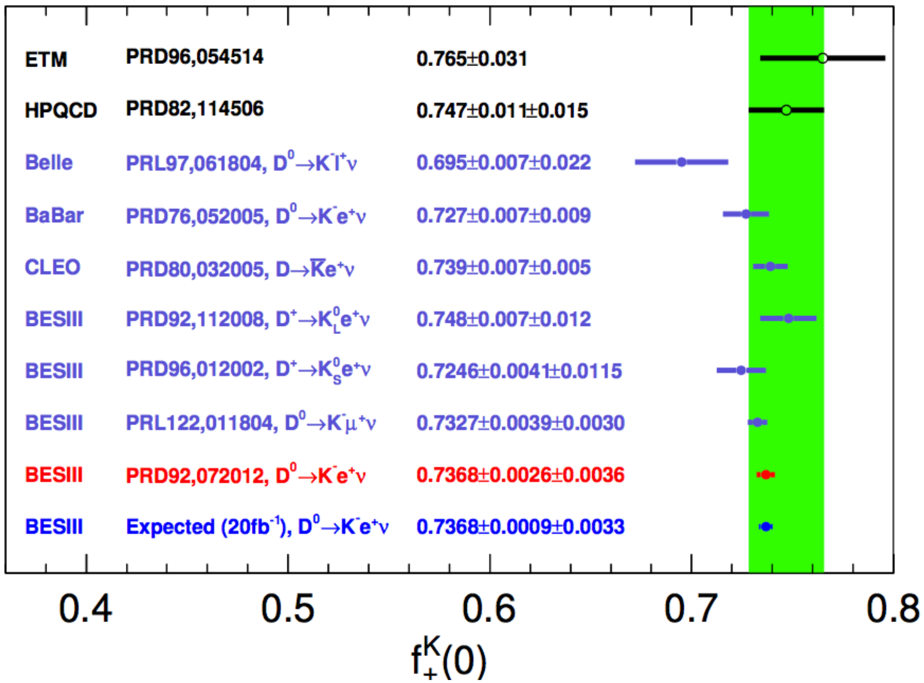
Prospects on the semi-leptonic decays

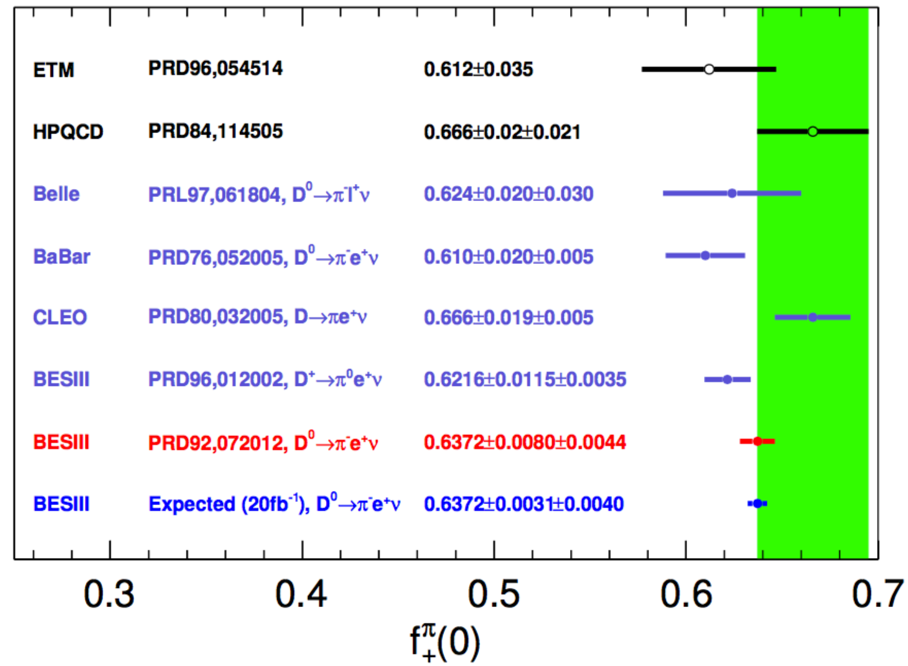
LFU test at STCF

	BESIII	BESIII	Belle	Belle II
Luminosity	2.9 fb^{-1}@3.773 GeV	20 fb^{-1}@3.773 GeV	0.28 ab^{-1}	50 ab^{-1}
$D^0 \to K^- e^+ \nu_e$	$0.4\%_{\rm stat.}$ $0.5\%_{\rm syst.}$	$0.2\%_{\rm stat.}0.4\%_{\rm syst.}$	$1.0\%_{\rm stat.}$ $3.2\%^*_{\rm syst.}$	$0.1\%_{\rm stat.}1.6\%^*_{\rm syst.}$
$D^0 \to K^- \mu^+ \nu_\mu$	$0.5\%_{\rm stat.}$ $0.4\%_{\rm syst.}$	$0.2\%_{\rm stat.}0.4\%_{\rm syst.}$		
$D^0 \to \pi^- e^+ \nu_e$	$1.3\%_{\rm stat.}$ $0.7\%_{\rm syst.}$	$0.5\%_{\rm stat.}0.4\%_{\rm stat.}$	$3.2\%_{\rm stat.}$ $4.8\%^*_{\rm syst.}$	$0.2\%_{\rm stat.}2.4\%^*_{\rm syst.}$
$D^0 \to \pi^- \mu^+ \nu_\mu$	NA	$0.8\%_{\rm stat.}0.8\%_{\rm syst.}$		
$D^0 \to K^{*-} e^+ \nu_e$				
r_V	$5.0\%_{\rm stat.}2.0\%_{\rm syst.}$	$2.0\%_{\rm stat.}2.0\%_{\rm syst.}$	–	–
r_A	$10.\%_{\rm stat.}2.0\%_{\rm syst.}$	$4.0\%_{\rm stat.}2.0\%_{\rm syst.}$	–	–
$D^0 \to a_0^-(980) e^+ \nu_e$	NA	$10.\%_{\rm stat.}5.0\%_{\rm syst.}$	–	–
$D^0 \to K_1^-(1270) e^+ \nu_e$	NA	$10.\%_{\rm stat.}5.0\%_{\rm syst.}$	–	–
$D^+ \to \bar{K}^0 e^+ \nu_e$	$0.6\%_{\rm stat.}$ $1.7\%_{\rm syst.}$	$0.2\%_{\rm stat.}1.0\%_{\rm syst.}$	–	–
$D^+ \to K_L^0 e^+ \nu_e$	$0.9\%_{\rm stat.}$ $1.6\%_{\rm syst.}$	$0.4\%_{\rm stat.}1.0\%_{\rm syst.}$	–	–
$D^+ \to \bar{K}^0 \mu^+ \nu_\mu$	NA	$0.3\%_{\rm stat.}1.0\%_{\rm syst.}$	–	–
$D^+ \to \bar{K}^{*0} e^+ \nu_e$				
$A_1(0)$	$1.7\%_{\rm stat.}$ $2.0\%_{\rm syst.}$	$0.7\%_{\rm stat.}1.0\%_{\rm syst.}$	–	–
r_V	$4.0\%_{\rm stat.}$ $0.5\%_{\rm syst.}$	$1.6\%_{\rm stat.}0.5\%_{\rm syst.}$	–	–
r_A	$5.0\%_{\rm stat.}$ $1.0\%_{\rm syst.}$	$2.0\%_{\rm stat.}1.0\%_{\rm syst.}$	–	–
$D^+ \to \pi^0 e^+ \nu_e$	$1.9\%_{\rm stat.}$ $0.5\%_{\rm syst.}$	$0.7\%_{\rm stat.}0.5\%_{\rm syst.}$	–	–
$D^+ \to \pi^0 \mu^+ \nu_\mu$	NA	$1.0\%_{\rm stat.}1.0\%_{\rm syst.}$	–	–
$D^+ \to \eta e^+ \nu_e$	$4.5\%_{\rm stat.}2.0\%_{\rm syst.}$	$2.0\%_{\rm stat.}2.0\%_{\rm syst.}$	–	–
$D^+ \to \eta' e^+ \nu_e$	NA	$10.\%_{\rm stat.}5.0\%_{\rm syst.}$	–	–
$D^+ \to \omega e^+ \nu_e$				
r_V	$7.2\%_{\rm stat.}$ $4.8\%_{\rm syst.}$	$3.0\%_{\rm stat.}2.0\%_{\rm syst.}$	–	–
r_A	$14\%_{\rm stat.}$ $5.0\%_{\rm syst.}$	$3.0\%_{\rm stat.}2.0\%_{\rm syst.}$		
$D^+ \to a_0^0(980) e^+ \nu_e$	NA	$10.\%_{\rm stat.}5.0\%_{\rm syst.}$		
$D^+ \to \bar{K}_1^0(1270) e^+ \nu_e$	NA	$10.\%_{\rm stat.}5.0\%_{\rm syst.}$		
$D^{0(+)} \to \rho^{-(0)} e^+ \nu_e$				
r_V	$5.0\%_{\rm stat.}4.0\%_{\rm syst.}$	$2.0\%_{\rm stat.}2.0\%_{\rm syst.}$		
r_A	$8.0\%_{\rm stat.}4.0\%_{\rm syst.}$	$3.0\%_{\rm stat.}2.0\%_{\rm syst.}$		

STCF will largely improve the precisions of the form factors over all the modes

Form factors $f_+^{D\to h}$





Crucial tests on the LQCD results

Lepton Flavor Universality

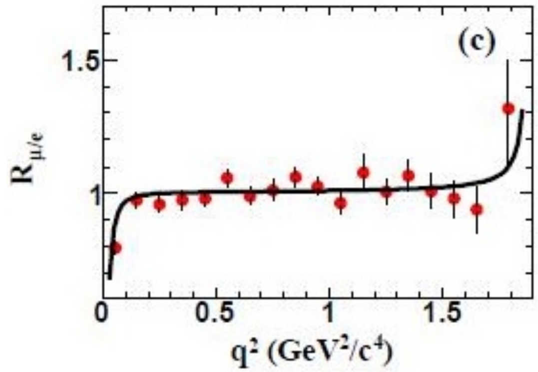
LFU is critical to test the SM and search for new physics beyond the SM

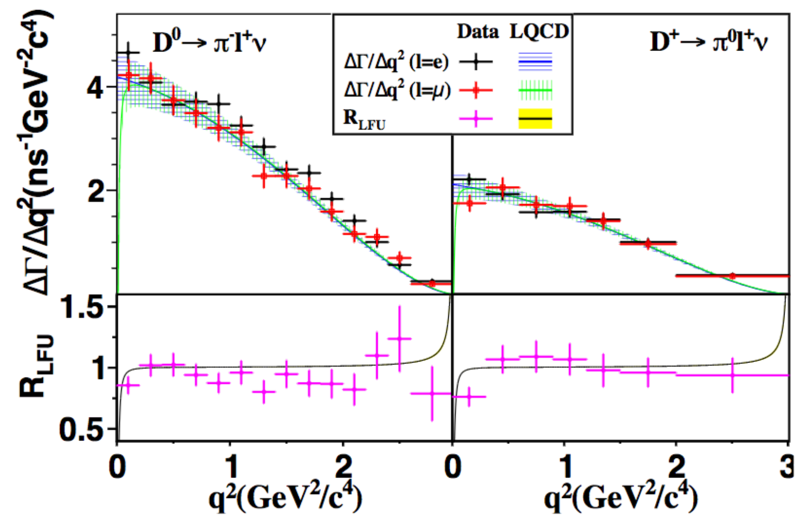
Pure-leptonic modes

$$R_{D^+_{(s)}} = \frac{\Gamma(D^+_{(s)} \to \tau^+\nu_\tau)}{\Gamma(D^+_{(s)} \to \mu^+\nu_\mu)} = \frac{m^2_{\tau^+}\left(1-\frac{m^2_{\tau^+}}{m^2_{D^+_{(s)}}}\right)^2}{m^2_{\mu^+}\left(1-\frac{m^2_{\mu^+}}{m^2_{D^+_{(s)}}}\right)^2}.$$

Semi-leptonic modes

$$R_{\mu/e} = \Gamma_{D^0\to K^-\mu^+\nu_\mu}/\Gamma_{D^0\to K^-e^+\nu_e}$$





1σ difference? 2σ difference?

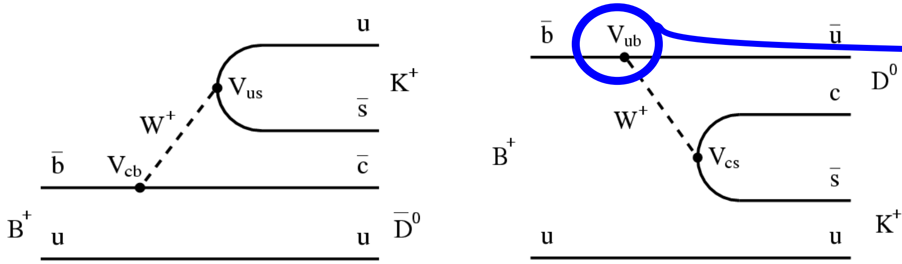
2.93/fb@3773MeV;
3.19/fb @ 4178MeV

	$R(D^+_s)$	$R(D^+)$	$R(K^-)$	$R(\bar{K}^0)$	$R(\pi^-)$	$R(\pi^0)$
SM	9.74(1)	2.66(1)	0.975(1)	0.975(1)	0.985(2)	0.985(2)
BESIII	10.19(52)	3.21(64)	0.974(14)	1.013(29)	0.922(37)	0.964(45)

- Large uncertainty from BESIII, dominant by statistically limited
- BESIII and STCF would improve them significantly

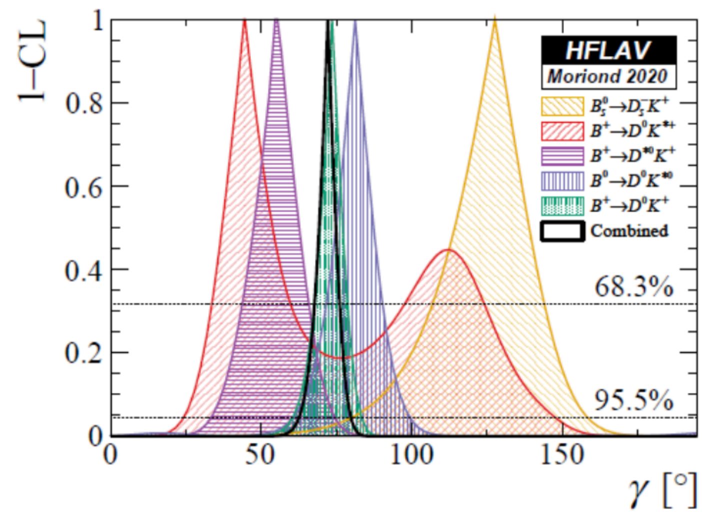
Determination of γ/ϕ_3 angle

- The cleanest way to extract γ is from B→DK decay



$$\frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D^0} K^+)} \equiv r_B e^{i(\delta_B + \phi_3)}$$

- Interference between tree-level decays; theoretically clean
- current uncertainty $\sigma(\gamma) \sim 5^0$
- however, theoretical relative error $\sim 10^{-7}$ (very small!)



Prog. Theor. Exp. Phys. 2020 083C01 (2020)

- Information of *D decay strong phase* is needed
  - Best way is to employ quantum coherence DD production at threshold

Determination of γ/φ$_3$ angle

Runs	Collected / Expected integrated luminosity	Year attained	γ/ϕ_3 sensitivity
LHCb Run-1 [7, 8 TeV]	3 fb^{-1}	2012	8°
LHCb Run-2 [13 TeV]	5 fb^{-1}	2018	4°
Belle II Run	50 ab^{-1}	2025	1.5°
LHCb upgrade I [14 TeV]	50 fb^{-1}	2030	< 1°
LHCb upgrade II [14 TeV]	300 fb^{-1}	(>)2035	< 0.4°

BESIII 20/fb:
σ(γ) ~0.4°

→ STCF is needed!

Decay mode	Quantity of interest
$D \to K^0_S\pi^+\pi^-$	c_i and s_i
$D \to K^0_S K^+K^-$	c_i and s_i
$D \to K^\pm\pi^\mp\pi^+\pi^-$	R, δ
$D \to K^+K^-\pi^+\pi^-$	c_i and s_i
$D \to \pi^+\pi^-\pi^+\pi^-$	F_+ or c_i and s_i
$D \to K^\pm\pi^\mp\pi^0$	R, δ
$D \to K^0_S K^\pm\pi^\mp$	R, δ
$D \to \pi^+\pi^-\pi^0$	F_+
$D \to K^0_S\pi^+\pi^-\pi^0$	F_+, c_i and s_i
$D \to K^+K^-\pi^0$	F_+
$D \to K^\pm\pi^\mp$	δ

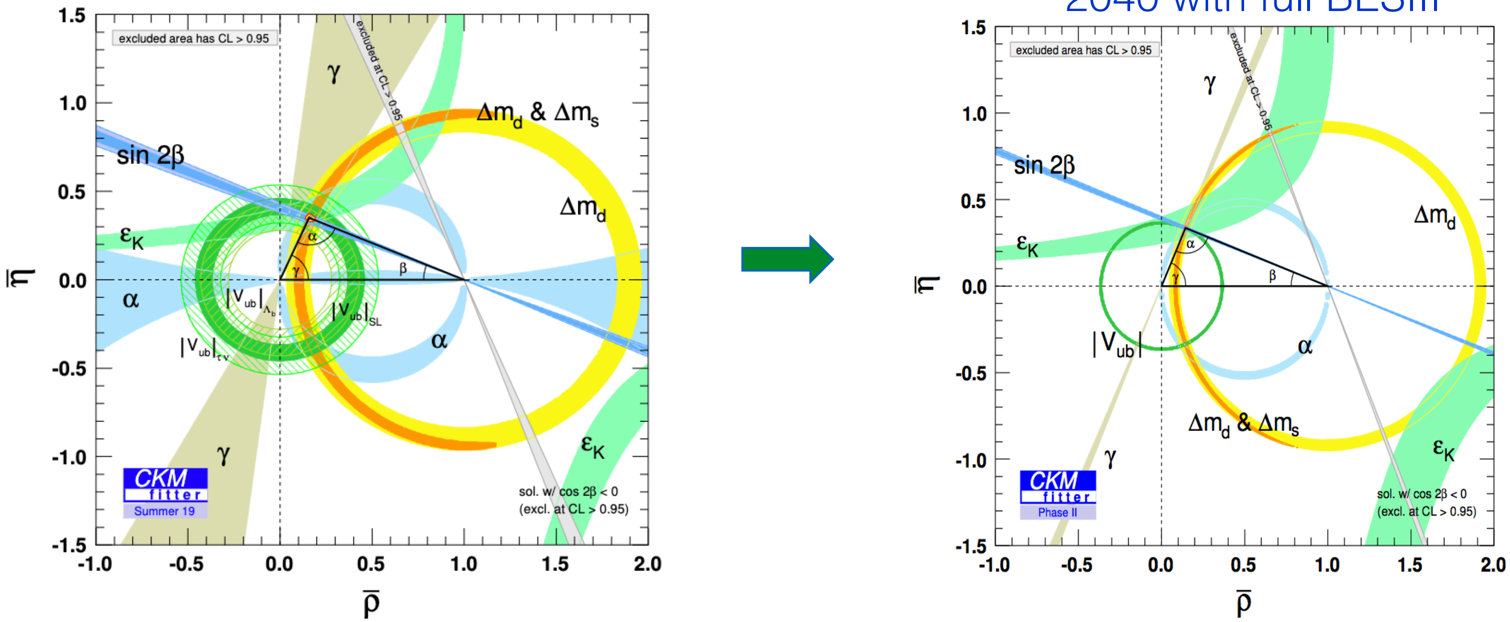
Three methods for exploiting interference (choice of D^0 decay modes):

- GLW: Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$
- ADS: Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$
  - With 1 ab^{-1} @ STCF : $\sigma(\cos\delta_{K\pi})$ ~0.007; $\sigma(\delta_{K\pi})$ ~2° → σ(γ) <0.5°
- BPGGSZ: Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\pi^+\pi^-$; high statistics; need precise Dalitz model
  - STCF reduces the contribution of *D* Dalitz model to a level of ~0.1°

Determination of γ/ϕ_3 angle in CKM

2019

2040 with full BESIII



STCF will provide complementary information on the strong phase and allow detailed comparisons in different models

$\boldsymbol{D^0}$-$\bar{\boldsymbol{D}}^0$ mixing and CPV at STCF

STCF provide a unique place for the study of $\boldsymbol{D^0}$-$\bar{\boldsymbol{D}}^0$ mixing and CPV by means of quantum coherence of $\boldsymbol{D^0}$ **and** $\bar{\boldsymbol{D}}^0$ produced through

$$\psi(3770) \to (D^0\bar{D}^0)_{\mathrm{CP}=-} \text{ or } \psi(4140) \to D^0\bar{D}^{*0} \to \pi^0(D^0\bar{D}^0)_{\mathrm{CP}=-} \text{ or } \gamma(D^0\bar{D}^0)_{\mathrm{CP}=+}$$

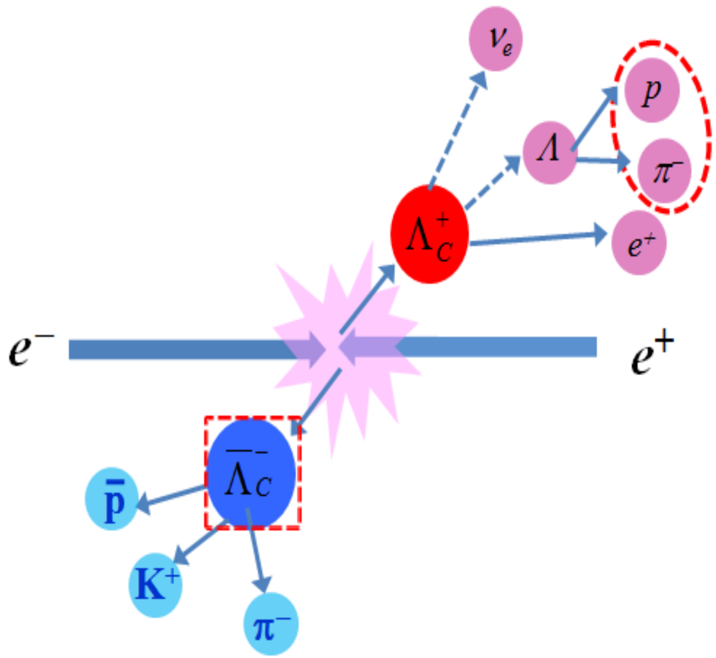
- Mixing rate $R_M = \frac{x^2+y^2}{2} \sim 10^{-5}$ with 1 ab^{-1} data at 3.773 GeV via same charged final states $(K^\pm\pi^\mp)(K^\pm\pi^\mp)$ or $(K^\pm l^\mp v)(K^\pm l^\mp v)$
- Mixing parameters and CPV parameters with 1 ab^{-1} data at 4009 MeV via coherent (C-even and C-odd) and incoherent process
- $\Delta A_{CP} \sim 10^{-3}$ for KK and ππ channels

Precision estimation at STCF

	1/ab @4009 MEV (only QC | QC+incoherent) (preliminary estimation)		BELLEII(50/ab) [PTEP2019, 123C01]	LHCb(50/fb) (SL | Prompt) [arXiv:1808.08865]	
$x(\%)$	0.036	0.035	0.03	0.024	0.012
$y(\%)$	0.023	0.023	0.02	0.019	0.013
r_{CP}	0.017	0.013	0.022	0.024	0.011
$\alpha_{CP}(^{\circ})$	1.3	1.0	1.5	1.7	0.48

- The only QC results: contains $D^0 \to K_S\pi\pi, D^0 \to K^-\pi^+\pi^0$ and general CP tag decay channels
- The QC+incoherent results: combines coherent and incoherent D^0 meson samples
- The BELLE II and LHCb results only contain incoherent $D^0 \to K_S\pi\pi$ channel

Charmed baryon decays

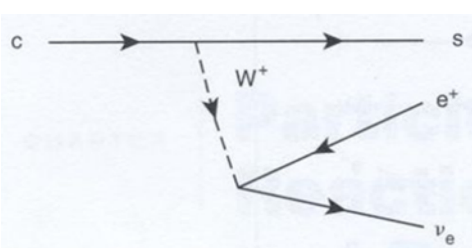


	Structure	J^P	Mass, MeV	Width,MeV	Decay
Λ_c^+	udc	$(1/2)^+$	2286.46 ± 0.14	(200 ± 6) fs	weak
Ξ_c^+	usc	$(1/2)^+$	$2467.8^{+0.4}_{-0.6}$	(442 ± 26) fs	weak
Ξ_c^0	dsc	$(1/2)^+$	$2470.88^{+0.34}_{-0.8}$	112^{+13}_{-10} fs	weak
Σ_c^{++}	uuc	$(1/2)^+$	2454.02 ± 0.18	2.23 ± 0.30	$\Lambda_c^+\pi^+$
Σ_c^+	udc	$(1/2)^+$	2452.9 ± 0.4	< 4.6	$\Lambda_c^+\pi^0$
Σ_c^0	ddc	$(1/2)^+$	2453.76 ± 0.18	2.2 ± 0.4	$\Lambda_c^+\pi^-$
$\Xi_c'^+$	usc	$(1/2)^+$	2575.6 ± 3.1	—	$\Xi_c^+\gamma$
$\Xi_c'^0$	dsc	$(1/2)^+$	2577.9 ± 2.9	—	$\Xi_c^0\gamma$
Ω_c^0	ssc	$(1/2)^+$	2695.2 ± 1.7	(69 ± 12) fs	weak
Σ_c^{*++}	uuc	$(3/2)^+$	2518.4 ± 0.6	14.9 ± 1.9	$\Lambda_c^+\pi^+$
Σ_c^{*+}	udc	$(3/2)^+$	2517.5 ± 2.3	< 17	$\Lambda_c^+\pi^0$
Σ_c^{*0}	ddc	$(3/2)^+$	2518.0 ± 0.5	16.1 ± 2.1	$\Lambda_c^+\pi^-$
Ξ_c^{*+}	usc	$(3/2)^+$	$2645.9^{+0.5}_{-0.6}$	< 3.1	$\Xi_c\pi$
Ξ_c^{*0}	dsc	$(3/2)^+$	2645.9 ± 0.5	< 5.5	$\Xi_c\pi$
Ω_c^{*0}	ssc	$(3/2)^+$	2765.9 ± 2.0	—	$\Omega_c^0\gamma$

Prospects at BESIII

4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}

	Leading hadronic decay	Typical two-body decay	Leading SL decay
Λ_c^+	$\mathcal{B}(K^-p\pi^+) =$ 2014: $(5.0 \pm 1.3)\%$ (26%) 2017(w/ BESIII): $(6.35 \pm 0.33)\%$ (5.2%) 5 fb^{-1}: $\frac{\delta\mathcal{B}}{\mathcal{B}} < 2\%$	$\mathcal{B}(K_S^0 p) =$ 2014: $(1.2 \pm 0.3)\%$ (26%) BESIII: $(1.52 \pm 0.08)\%$(5.6%) 5 fb^{-1}: $\frac{\delta\mathcal{B}}{\mathcal{B}} < 2\%$	$\mathcal{B}(\Lambda e^+\nu_e) =$ 2014: $(2.1 \pm 0.6)\%$ (29%) BESIII: $(3.63 \pm 0.43)\%$ (12%) 5 fb^{-1}: $\frac{\delta\mathcal{B}}{\mathcal{B}} \sim 3.3\%$
D^0	$\mathcal{B}(K^-\pi^+) = (3.89 \pm 0.04)\%$ (1.0%)	$\mathcal{B}(K_S^0\pi^0) = (1.19 \pm 0.04)\%$ (3.4%)	$\mathcal{B}(K^-e^+\nu_e) = (3.53 \pm 0.03)\%$ (0.8%)
D^+	$\mathcal{B}(K^-\pi^+\pi^+) = (8.98 \pm 0.28)\%$ (3.1%)	$\mathcal{B}(K_S^0\pi^+) = (1.47 \pm 0.08)\%$ (5.4%)	$\mathcal{B}(K_S^0 e^+\nu_e) = (4.41 \pm 0.07)\%$ (1.5%)
D_s^+	$\mathcal{B}(K^-K^+\pi^+) = (5.45 \pm 0.17)\%$ (3.8%)	$\mathcal{B}(K_S^0 K^+) = (1.40 \pm 0.05)\%$ (3.6%)	$\mathcal{B}(\phi e^+\nu_e) = (2.39 \pm 0.23)\%$ (9.6%)



Mode	Expected rate (%)	Relative uncertainty (%)
$\Lambda_c^+ \to \Lambda l^+\nu$	3.6 [94, 95]	3.3
$\Lambda_c^+ \to \Lambda^* l^+\nu$	0.7 [96, 97]	10
$\Lambda_c^+ \to NKe^+\nu_e$	0.7 [96]	10
$\Lambda_c^+ \to \Sigma\pi l^+\nu$	0.7 [96]	10
$\Lambda_c^+ \to ne^+\nu_e$	0.2 [94, 98, 99]	17

first measurement

STCF: precision studies of the charmed baryon decays

Era of precision study of the charmed baryon (Λ_c, Ξ_c and Ω_c) decays
to help developing more reliable QCD-derived models in charm sector

- **Hadronic decays**:
  to explore as-yet-unmeasured channels and understand full picture of intermediate structures in charmed baryon decays, esp., those with neutron/Σ/Ξ particles
- **Semi-leptonic decays**:
  to test LQCD calculations and LFU
- CPV in charmed baryon: BP and BV two-body decay asymmetry, charge-dependent rate of SCS
- Charmed Baryons Spectroscopy : (63 P-wave states from QM, less than 20 are observed!)
- Rare decays: LFV, BNV, FCNC

STCF will provide very precise measurements of their overall decays, up to the unprecedented level of $10^{-6} \sim 10^{-7}$

Summary

- **BESIII and STCF** are **the crucial precision frontier**
- **Important playground for studying non-perturbtive QCD, constrain EW theory and test the SM**
  - ✓ CKM matrix elements
  - ✓ LQCD calibration
  - ✓ Search for violation of LFU in charm sector
  - ✓ Precision measurement of the charmed baryon decays
- Complementary to Belle II and LHCb in understanding the QCD/EW models and searching for new physics

Thank you!

谢谢！

Data samples

Data samples with 1 ab^{-1} integral luminosity

	STCF					Belle II		
Data Set	process	σ/nb	N	ST eff./%	ST N	σ/nb	N	Tag N
J/ψ	–	–	1.0×10^{12}	–	–	–	–	–
$\psi(2S)$	–	–	3.0×10^{11}	–	–	–	–	–
D^0	$D^0\bar{D}^0(3.77)$	~ 3.6	3.6×10^9	10.8	0.78×10^9	–	1.4×10^9	–
D^+	$D^+D^-(3.77)$	~ 2.8	2.8×10^9	9.4	0.53×10^9	–	7.7×10^8	–
D_s	$D_sD_s^*(4.18)$	~ 0.9	0.9×10^9	6.0	0.11×10^9	–	2.5×10^8	–
τ^+	$\tau^+\tau^-(3.68)$	~ 2.4	2.4×10^9	–	–	0.9	0.9×10^9	–
	$\tau^+\tau^-(4.25)$	~ 3.6	3.5×10^9	–	–	–	–	–
Λ_c	$\Lambda_c\Lambda_c(4.64)$	~ 0.6	5.5×10^8	5.0	0.55×10^8	–	1.6×10^8	$3.6 \times 10^{4*}$

The luminosity is 1.0 ab^{-1}. * process $e^+e^- \to D^{(*)-}\bar{p}\pi^+\Lambda_c^+$.

- Belle-II (50/ab) has 50~100 times more statistics
- STCF is expected to have higher detection efficiency
- STCF has low backgrounds for productions at threshold

D^0 mixing and CPV parameters

- Three kinds of $D^0\bar{D}^0$ samples can be used @4009MeV
  - **Quantum-incoherent flavor specific D^0 samples: $D^{*+} \to D^0\pi^+$**
    - Help to improve precision of strong-phase difference measurement
    - Be used to constrain the charm mixing and CPV parameters
  - **Quantum-coherent C-even $D^0\bar{D}^0$ samples: $D^{*0}\bar{D}^0 \to D^0\bar{D}^0\gamma$**
    - Be used to perform charm mixing and CPV parameters measurements
      - The interference effect, containing mixing and CPV, is doubled compare to incoherent case
    - Help to constrain the strong-phase difference and CP fraction measurements
  - **Quantum-coherent C-odd $D^0\bar{D}^0$ samples: $D^{*0}\bar{D}^0 \to D^0\bar{D}^0\pi^0$**
    - Same as $D^0\bar{D}^0$ samples @3770, improve precision of strong-phase difference measurements and CP fraction measurements

	BES III 10^{33} cm^{-2}s^{-1}	STCF 10^{35}cm^{-2}s^{-1} (1ab^{-1})
J/ψ	10×10^{9}	10×10^{11}
$\psi(2S)$	3×10^{9}	3×10^{11}
D(3.773GeV)	6×10^{7}	6×10^{9}
Ds (4.17 GeV)	1×10^{7}	1×10^{9}
$\tau^{+}\tau^{-}$ (3.68GeV)		2.4×10^{9}
$\tau^{+}\tau^{-}$ (4.25GeV)	3×10^{7}	3.5×10^{9}
$\Lambda_c^{+}\Lambda_c^{-}$(4.64GeV)	3×10^{6}	6×10^{8}

Charm mixing and CPV parameters

- For quantum-incoherent D^0 meson samples[1]:

$$\overline{P}'\left(m_{12}^2, m_{13}^2\right) = a_0\overline{P} + a_1 r_{CP}^{-2} P + r_{CP}^{-1}\sqrt{P\overline{P}}\left(C^- a_2 + S^- a_3\right)$$

- For quantum-coherent $D^0\overline{D}^0$ samples:

$$r_{CP}e^{i\alpha_{CP}} = \frac{q}{p},$$
$$S^{\pm} = \sin\left(\Delta\delta_D \pm \alpha_{CP}\right),$$
$$C^{\pm} = \cos\left(\Delta\delta_D \pm \alpha_{CP}\right),$$

$$a_0 = \frac{1}{2}\left(\frac{1}{1-y_D^2} + \frac{1}{1+x_D^2}\right) = 1 + \frac{1}{2}\left(-x_D^2 + y_D^2\right) + O\left((x_D + y_D)^3\right),$$
$$a_1 = \frac{1}{2}\left(\frac{1}{1-y_D^2} - \frac{1}{1+x_D^2}\right) = \frac{1}{2}\left(x_D^2 + y_D^2\right) + O\left((x_D + y_D)^3\right),$$
$$a_2 = \frac{y_D}{1-y_D^2} = y_D + O\left((x_D + y_D)^3\right),$$
$$a_3 = \frac{x_D}{1+x_D^2} = x_D + O\left((x_D + y_D)^3\right).$$

$$\begin{aligned}
P_{corr}^{\mathcal{C}}\left(\left(m_{12}^2\right)_1, \left(m_{13}^2\right)_1, \left(m_{12}^2\right)_2, \left(m_{13}^2\right)_2\right) = b_0^{\mathcal{C}} &\left[P_1\overline{P}_2 + \overline{P}_1 P_2 + 2\mathcal{C}\sqrt{P_1\overline{P}_1 P_2\overline{P}_2}\left(C_1C_2 + S_1S_2\right)\right] \\
+b_1^{\mathcal{C}} &\left[r_{CP}^{-2}P_1P_2 + r_{CP}^2\overline{P}_1\overline{P}_2 + 2\mathcal{C}\sqrt{P_1\overline{P}_1P_2\overline{P}_2}\left(C_1^+C_2^+ - S_1^+S_2^+\right)\right] \\
+b_2^{\mathcal{C}} &\left[\sqrt{P_2\overline{P}_2}C_2^+\left(r_{CP}\overline{P}_1 + r_{CP}^{-1}P_1\right) + \mathcal{C}\sqrt{P_1\overline{P}_1}C_1^+\left(r_{CP}\overline{P}_2 + r_{CP}^{-1}P_2\right)\right] \\
+b_3^{\mathcal{C}} &\left[\sqrt{P_2\overline{P}_2}S_2^+\left(r_{CP}\overline{P}_1 - r_{CP}^{-1}P_1\right) + \mathcal{C}\sqrt{P_1\overline{P}_1}S_1^+\left(r_{CP}\overline{P}_2 - r_{CP}^{-1}P_2\right)\right],
\end{aligned}$$

$$b_0^{\mathcal{C}} = \frac{1}{2}\left[\frac{1+\mathcal{C}y_D^2}{\left(1-y_D^2\right)^2} + \frac{1-\mathcal{C}x_D^2}{\left(1+x_D^2\right)^2}\right] \approx a_0 + \frac{\mathcal{C}+1}{2}\left(-x_D^2 + y_D^2\right),$$
$$b_1^{\mathcal{C}} = \frac{1}{2}\left[\frac{1+\mathcal{C}y_D^2}{\left(1-y_D^2\right)^2} - \frac{1-\mathcal{C}x_D^2}{\left(1+x_D^2\right)^2}\right] \approx (\mathcal{C}+2)\, a_1,$$
$$b_2^{\mathcal{C}} = \frac{(1+\mathcal{C})\, y_D}{\left(1-y_D^2\right)^2} \approx (1+\mathcal{C})\, a_2,$$
$$b_3^{\mathcal{C}} = \frac{(1+\mathcal{C})\, x_D}{\left(1+x_D^2\right)^2} \approx (1+\mathcal{C})\, a_3,$$

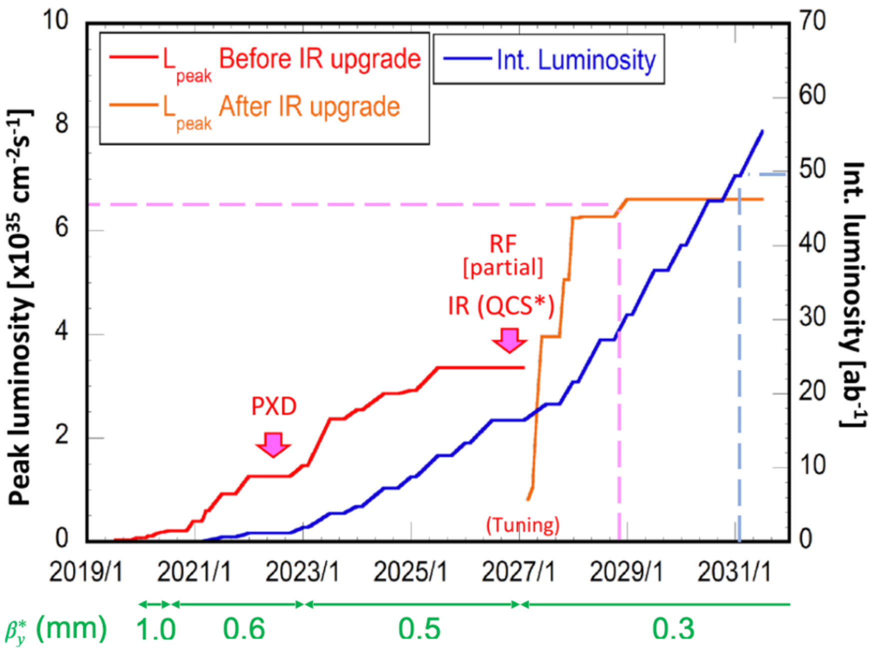
Integral Luminosity of STCF

- No Synchrotron radiation mode, assume running time 9 months/year
- Assume data taking efficiency 90%

$$0.5 \times 10^{35}\text{cm}^{-2}\text{s}^{-1} \times 86400\text{s} \times 270\text{days} \times 90\% \sim \mathbf{1.0ab^{-1}/year}$$

10 years data taking, total 20 ab^{-1} conservatively

Excellent opportunities for the τ-charm physics



at Belle II

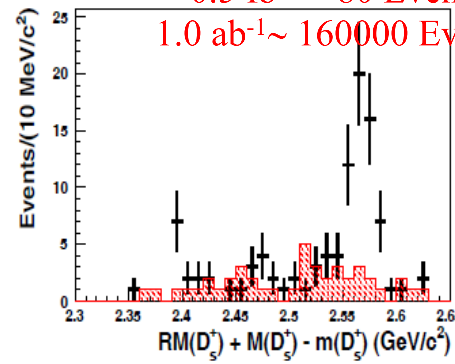
- each 1 ab^{-1} dataset provides
  - $\sim 1.1 \times 10^9$ $B\bar{B}$ $\Rightarrow$ a B-factory;
  - $\sim 1.3 \times 10^9$ $c\bar{c}$ $\Rightarrow$ a charm factory;
  - $\sim 0.9 \times 10^9$ $\tau^+\tau^-$ $\Rightarrow$ a τ factory;
  - wide $E_{CM}^{eff.}$=[0.5-10] GeV via ISR.

Features in studying charm hadron decays

	BESIII/ STCF	Belle II	LHCb
Production yields	★★	★★★★	★★★★★
Background level	★★★★★	★★★	★★
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★★	★★
Neutron/K_L mode	★★★★★	★★★	☆
Photon-involved	★★★★★	★★★★	★
Absolute measurement	★★★★★	★★★	☆

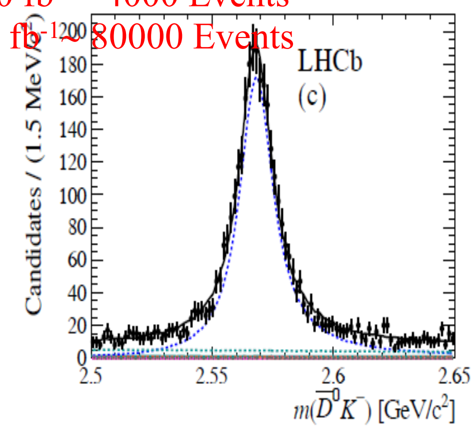
0.5 fb^{-1} ~ 80 Events

1.0 ab^{-1}~ 160000 Events



3.0 fb^{-1}~ 4000 Events

60 fb^{-1}~ 80000 Events



- Most are precision measurements, which are mostly dominant by the systematic uncertainty
- STCF has overall advantages in several studies